Appendix A

Estimation of State Properties

A1: Simulation Model for AAVAR System

In order to determine the data that are not available from the online during the normal operation of the AAVAR plant at GNFC, Bharuch, Gujarat for the purpose of carrying out exergoeconomic optimization of the brine chilling unit using AAVAR system with steam from an independent boiler as heat energy source, a simulation model using EES solver is used. This Appendix A1 gives relations for the mass, energy and concentration balance for the components such as generator, rectifier of the AAVAR plant, energy balance for condenser, throttle valve and evaporator, effectiveness, mass and energy (enthalpy) balance for heat exchangers (RHX05 and RHX 06), energy balance for absorber and work done on absorber pump along with an expression for theoretical C.O.P.

Generator

$$\dot{m}_1 + \dot{m}_4 = \dot{m}_2 + \dot{m}_3 \quad \text{(A1.1)}$$

$$\dot{m}_1 h_1 + \dot{m}_4 h_4 - \dot{m}_2 h_2 - \dot{m}_3 h_3 + \dot{Q}_g = 0 \quad \text{(A1.2)}$$

$$\dot{m}_1 x_1 + \dot{m}_4 x_4 = \dot{m}_2 x_2 + \dot{m}_3 x_3 \quad \text{(A1.3)}$$

Rectifier

$$\dot{m}_3 + \dot{m}_{18} = \dot{m}_4 + \dot{m}_5 \quad \text{(A1.4)}$$

$$\dot{m}_3 h_3 + \dot{m}_{18} h_6 - \dot{m}_4 h_4 - \dot{m}_5 h_5 = 0 \quad \text{(A1.5)}$$

$$\dot{m}_3 x_3 + \dot{m}_{18} x_6 = \dot{m}_4 x_4 + \dot{m}_5 x_5 \quad \text{(A1.6)}$$

$$\dot{m}_5 - \dot{m}_{18} = \dot{m}_{evap} + \dot{m}_{10} \quad \text{(A1.7)}$$

Condenser

$$Q_c = \dot{m}_5(h_5 - h_6) \tag{A1.8}$$

Heat exchanger 06

$$\chi_{06} = \frac{\dot{m}_6(h_6 - h_7)}{\dot{m}_{10}(h_6 - h_{7m})} \quad \text{Where } h_{7m} \text{ is minimum possible enthalpy.} \tag{A1.9}$$

$$\dot{m}_6 = \dot{m}_{evap} + \dot{m}_{10} \tag{A1.10}$$

$$\dot{m}_6(h_6 - h_7) = \dot{m}_{10}(h_{11} - h_{12}) \tag{A1.11}$$

Heat exchanger 05

$$\chi_{05} = \frac{\dot{m}_6(h_7 - h_8)}{\dot{m}_{evap}(h_7 - h_{8m})} \quad \text{Where } h_{8m} \text{ is minimum possible enthalpy.} \tag{A1.12}$$

$$\dot{m}_6(h_7 - h_8) = \dot{m}_{evap}(h_{13} - h_{12}) \tag{A1.13}$$

Throttle Valve

$$h_8 = h_9 \tag{A1.14}$$

Evaporator

$$Q_e = \dot{m}_{evap}(h_{12} - h_9) \tag{A1.15}$$

Absorber

$$\dot{m}_1(h_1 - h_{15}) = \dot{m}_2(h_2 - h_{16}) \tag{A1.16}$$

$$\dot{m}_2\, h_{17} + \dot{m}_{10}\, h_{11} + \dot{m}_{evap}\, h_{13} - \dot{m}_1\, h_{14} - Q_a = 0 \tag{A1.17}$$

$$w_p = \frac{v_{14}(P_G - P_a)}{\eta_p} \tag{A1.18}$$

$$W_p = m_1 w_p \tag{A1.19}$$

$$\varepsilon_{02} = \frac{(h_2 - h_{16})}{(h_2 - h_{16m})} \tag{A1.20}$$

Solving Eqs. A1.1 to A1.20, using EES solver, the properties at stations 1 to 18 can be estimated.

A2: Energy Balance at Stations 21 to 34

This part of the Appendix deals with energy balance for various components carried out to estimate properties at stations 21 to 34 that are not readily available through online data during the normal operation of the plant.

A2.1 Energy Balance at Condenser

Condenser condenses the ammonia vapour from rectifier and cools up to 40°C. From the system simulation, it is observed that the heat loss from the condenser is 3638 kW. The cooling water flow rate at condenser is 88.6 kg/sec with inlet temperature at station 23 is 33°C.

$$Q_c = m_{cwc} C_{cw} (T_{cwi} - T_{cwo}) \tag{A2.1}$$

Considering the specific heat of cooling water $C_{cw} = 4.187 \text{kJ/kgK}$, the outlet temperature of cooling water at condenser exit (station 24) is found to be 42.8°C

A2.2 Energy Balance at Absorber

From the system simulation, it is observed that the heat rejected at absorber is 5405 kW. For absorber the cooling water flow rate is 125 kg/sec at 33°C at station 25.

$$Q_a = m_{cwa} C_{cw} (T_{cwi} - T_{cwo}) \tag{A2.2}$$

From energy balance, it is observed that the temperature of cooling water at station 26 is 43.33°C

A2.3 Energy Balance at Pre-cooler-1

At Pre-cooler-1, liquid ammonia at 4 bar saturated enters at station 31. Its temperature is found to be -1.89°C. The exit temperature of ammonia at station 32 is measured to be 6.4°C. At given temperature and 4 bar pressure, the enthalpy of ammonia at stations 31 and 32 is found to be 191.3 and 1482 kJ/kg, respectively using EES solver. The brine enters the Pre-cooler-1 at 24.7°C and the specific heat of brine is found to be 3.08 using EES solver.

From energy balance across Pre-cooler-1

$$m_{brine}C_{brine}(T_{29}-T_{30}) = m_{ammonia,pc1}(h_{32}-h_{31}) \tag{A2.3}$$

Solving Eq.A2.3, the temperature of brine at station 30 is found to be 15.9°C.